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Basic Investigations of the Radam Effect

RONALD G. NEWBURGH

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ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFISS AIR FORCE BASE, NEW YORK 13441

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This report summarizes the basic investigations of the RADAM effect (the radar detection of agitated metals) for the Air Force. The work reported was done by the Rome Air Development Center (Electromagnetic Sciences Division) the Polytechnic Institute of New York, and the Stanford Research Institute. AFOSR supervised the contractual work. The three main causes of the effect are subsystem motion, structural vibrations, and junction effects. The phenomena have been classified and are understood in terms of basic physical processes.

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Basic Investigations of the Radam Effect

1. INTRODUCTION

The term RADAM is an acronym for the radar detection of agitated metals. Motion of a target is often accompanied by a modulation of its radar cross section (RCS). There are several possible causes for this modulation.

The goal of these investigations has been to determine both the efficiency of the different physical processes in causing the modulation, and the magnitudes of the modulation compared with the cross section of the stationary target.

The three main causes of the modulation are subsystem motion, structural vibrations, and junction effects. Subsystem motion is the relative motion of one part of the target with respect to the rest. Examples of this are rotation of propellers, tank treads, and scanning antennas. Such motions produce effects obviously related to doppler phenomena. Another example of such an effect is jet engine modulation (JEM). This is a separate subject and will not be considered here, although it is representative of the phenomena.

Structural vibrations include engine induced vibration. It will occur with the vehicle at rest while the engine is running. A second type of vibration is that of airframes, such as that observed in wing flutter. Structures have characteristic vibrational frequencies that, when excited by a driving force such as an engine, may be useful in the field of target signatures.

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Junction effects fall naturally into two types. The first is switching or the intermittent opening and closing of a junction. Such switching may be periodic or random. The second is a junction diode effect, a nonlinear effect originating in the strain sensitive electric behavior of composite conducting surfaces. A metal with an oxide surface, often comprising more than one chemical compound, may show quite complicated behavior when illuminated by microwave radiation. The complexity may be further compounded if motion causes time-varying electrical characteristics of the oxide.

All these effects may cause modulation of the RCS. It is important to separate these effects and to assess the magnitude of each. If, for example, one cannot see a junction diode effect in the presence of rotational subsystem motion, there is hardly any point in looking for junction diode effects for helicopter signatures. Though an obvious statement, it must be remembered.

The Air Force research program into RADAM phenomena began in 1974. Coordinated goals were identified for in-house research (RADC/EEC) under Dr. R. Mack (RADC/EEC), and for contractual research under the supervision of Dr. G. Knausenberger (AFOSR/NE). During most of the period during which the research was done, Dr. Mack served as the overall focal point for purposes of coordination and briefing. When he left in 1977, Dr. R. Newburgh (RADC/EEC) assumed this role.

2. ROME AIR DEVELOPMENT CENTER – ELECTROMAGNETIC SCIENCES DIVISION (RADC/EEC)

The Electromagnetic Systems Concepts Branch investigated subsystem motions and structural vibrations. The investigations were both theoretical and experimental. Several people worked on the program and their results will be summarized in turn.

Dr. R. Newburgh of RADC/EE and Dr. G. Borgiotti (the latter a National Research Council Senior Resident Research Associate at RADC/EE) examined theoretically the backscattered spectra from rotating and vibrating short wires.[1,2] By treating short wires, the problem was simplified to scattering from a point dipole or simple Rayleigh scatterer. Rotation produces an amplitude modulation, with a spectrum dependent on the state of polarization of the incident field. The

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1. Newburgh, R.G., and Borgiotti, G.V. (1975) Backscattered Spectra From Rotating and Vibrating Short Wires and Their Relation to the Identification Problem, Physical Sciences Research Papers, No. 633, AFCRL-TR-75-0298.

2. Newburgh, R.G., and Borgiotti, G.V. (1975) Short wire as a microwave analogue to molecular raman scatterers, Applied Optics 14:2727.

vibrating wire produces a phase modulated spectrum. In both instances, the spectra provide a determination of the frequency of the periodic motion. The two cases serve as models for the more complicated periodic motions that are met in practice.

Professor R. E. Kleinman of the University of Delaware, while also a National Research Council Senior Resident Research Associate at RADC/EE, began a detailed analysis of the scattering problem for a plane wave incident upon a perfectly conducting linearly oscillating object.[3] He continued his work at the University of Delaware under the sponsorship of the Mathematical Directorate of AFOSR. The analysis showed that the scattered far field of the vibrating target differs from that of the stationary target in phase only. The oscillation, which is assumed to be periodic, imposes the same period on the modulation of the field. Spectral analysis of the modulation showed that the power distribution varies with the wave form of the target motion, the wavelength of the incident field, and the magnitude of the projections of the oscillation in the directions of incidence and scattering. Power spectra were calculated for square, triangular, and sinusoidal target motions. In general, the power content in the higher harmonics increased with carrier frequency and magnitude of oscillation. For backscattering from an object moving sinusoidally in a direction parallel to the direction of incidence, the power in the first harmonics exceeds that at the carrier frequency when d, the magnitude of the oscillation, is greater than 0.23λ.

Dr. R. Mack carried out a parallel experimental program to complement Kleinman's theoretical study.[4, 5] Measurements of the phase modulation of the field scattered from a vibrating disk at X-band confirmed these calculations. The experimental arrangement was built around a cw backscatter equipment operating at 10 GHz that used separate tunnel antennas for transmitting and receiving in order to eliminate all extraneous reflections. Phase modulations introduced by target oscillations with displacements as small as ±0.001 in. were readily detected as were amplitude modulations of a few percent.

These results suggest possibilities and limitations for use of subsystem motions in identification. Linearly oscillating motions produce phase modulations only, while the envelope of the spectrum depends on the oscillation amplitude. Therefore, the envelope cannot be used as a unique target characteristic. However,

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3. Kleinman, R. E. (1975) Electromagnetic Scattering by a Linearly Oscillating Target, Physical Sciences Research Papers, No. 648, AFCRL-TR-75-0554.
4. Mack, R. B. (1977) Measured Backscatter Modulation from Linearly Oscillating Metal Disks, RADC-TR-77-285.
5. Kleinman, R. E., and Mack, R. B. (1978) Scattering by Linearly Vibrating Objects, to be published.

some features of the spectra such as spacing of the spectral lines and power levels in the sidebands may be usable. For rotating plates, the envelope shape does not change appreciably and may be useful as a unique characteristic.

In addition, some qualitative work was done at the Ipswich Test Facility with "penetratable targets," that is, targets into which the electromagnetic energy can penetrate. The question was asked, what is the difference between the return from a stationary motor vehicle and that from the same vehicle, still stationary but with the motor idling? Modulations were observed, identified as being caused by the fan belt and the pulley on the alternator. The modulation originating in the fan belt motion was some 40 dB below the skinline, the return from the truck when viewed head-on.

3. STANFORD RESEARCH INSTITUTE (SRI)
(Dr. O.G. Villard, L.E. Sweeney, A. Bahr)

The title of the SRI contract* is "Analysis of Radar Detection of Agitated Metals (RADAM)." In their original proposal, they proposed to identify and to isolate from each other the physical processes and mechanisms that contribute to the formation of a RADAM target signature. In addition, they proposed to investigate the physical processes and mechanisms contributing to the recognition process for RADAM target signatures and to separate RADAM contact effects from target scintillation. It was soon evident that the scope of the intermittent contact phenomena would be great enough to absorb their whole effort in the first year of the contract.

In the first year, they postulated a model to explain the abrupt modulation of scattered energy that occurs when a contact in the target opens or closes. The model ascribed the modulation to the redistribution of surface current taking place when an electrical contact in the target changes its state. They assumed that the current redistribution was describable in terms of time-varying impedances connected across the points of contact. The switching time scale is determined by the RF period of the radiation, which is typically a few nsec. For instantaneous switching the change in the state of the contact occurs in a time small compared with the product of the RF period and the Q of the target. For quasisteady state switching, the change occurs very slowly compared with the RF period. The experimental program was based on the impedance-loaded, scatterer model.

To examine this model they made brass dipole rods divided into two halves by a 45-deg cut. The three dipoles had lengths corresponding to half-wavelength resonant frequencies of 500, 800, and 1100 MHz. The contact between the

*Contract F44620-75-C-0045 with AFOSR.

two halves was interrupted periodically, the interruption frequency being of the order of 1 Hz.

From their experiments[6] they concluded the following:

(1) For a given dipole the intermittent contact effect is more readily observed at some frequencies than at others. This conclusion follows from the fact that the amount of sideband energy in the spectrally broadened scattered signal depends in part on the differences between the radar cross sections and phases of the scattering states of the target. (There are two states, open and closed.) These differences will be greatest if one (or more) of the states corresponds to a target resonance. Conversely, if the characteristic dimensions of the targets are resonant for a given frequency, the effect is observed at that frequency.

(2) For given scattering states, the distribution of energy in the sidebands will depend on the characteristics of "contact bounce," a function of the mechanical design of the contact.

Having established the validity of the redistribution of the surface currents when switching occurs, and the usefulness of the impedance-loaded, scatterer model in describing this redistribution, they continued studying the intermittent contact effect. The main conclusions of the second year's work are:

(1) The scattered spectral energy is determined by the ratio of the target dimension to the electromagnetic wavelength and the frequency dependence of the impedance associated with the contacts.

(2) The observed modulation on the backscattered signal is a function of both the number and location of the contacts within the target and also on their phasing.

(3) Modulation produced by intermittent contacts is like a square wave, whereas that due to subsystem motion is sinusoidal. These differences may be useful in separating the two types.

(4) Some work was done with junction effects, that is, contacts with different materials were studied. This work is similar to that of PINY (see Section 4). The effects were of two kinds: the amount of amplitude and phase change between open and closed states, and the time scale of the change. The observed differences were correlated with the resistance of the contact, namely, whether it was high or low.

SRI has completed its work on the physical understanding of intermittent contacts as a RADAM phenomenon. In analyzing VHF backscatter data taken from tracked vehicles (a tank and an APC) and a truck for AFAL under an AFOSR contract, they have shown that intermittent-contact RADAM effects may be applicable to the problem of tactical target identification. They have demonstrated that:

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6. Bahr, A.J., Frank, V.R., Petro, J.P., and Sweeney, L.E. Jr. (1977) Radar scattering from intermittently contacting metal targets, IEEE Transactions on Antennas and Propagation, AP-25:512.

(1) RADAM transients can be separated from other time variations in the VHF backscatter amplitude and used to trigger pulse-counting circuitry.

(2) RADAM-pulse signatures can be developed and perhaps used to identify different types of tracked vehicles. Vehicles without tracks (for example, trucks) produce far fewer RADAM pulses.

(3) Identification can be done automatically, since a certain range of pulse lengths corresponds to a certain type of vehicle.

It must be emphasized that these results and conclusions are based on limited data. More data are required before practical exploitation of this phenomenon is attempted. Continuation of this work falls naturally into the 6.2 area.

4. PINY (Dr. H. Juretschke)

The title of the PINY contract* is "Microwave Reflections from Vibrating Inhomogeneous Conducting Surfaces." As stated in their initial proposal the effort has three parts:

(1) Fundamental properties of oxide layers and junctions.

(2) High frequency properties of composite surfaces.

(3) Electromagnetic scattering from composite surfaces.

More specifically, they are concerned with the strain dependency of the electrical properties introduced by mechanical vibration and the relation of this dependency to the modulation of the radar return from vibrating metallic equipment.

To be able to apply this relation, the PINY program developed plausible models of composite surfaces. The first model assumed a homogeneous surface criss-crossed by geometrical fissures whose depth is comparable to or greater than skin depth. These fissures influence the flow of surface current, because of both the fissure geometry and the electrical properties of the material in the gaps. The radar modulations are then related to changes in the fissure geometry as well as in the gap electrical properties, changes caused by mechanical vibration of the surface.

The second model assumes inhomogeneity of the surface on a microscopic scale, because of the random, uncontrolled growth of oxides on exposed metal surfaces. The surface may then consist of a collection of oxides with widely varying electrical properties, which are further affected by mechanical vibrations.

The first year's results are summarized here:

(1) PINY set up an X-band cavity with a capacitively coupled end wall that can be driven acoustically. Measurement of the cavity resonance gives the shift in

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*Grant AFOSR-76-3030.

resonant frequency and the cavity Q as a function of acoustic amplitude. From these data, one computes the change of microwave properties of the end plate of the cavity as a function of vibration. Since the end plate is demountable, the cavity is suitable for the study of any material from which end plates can be made. Moreover, a plate may be given various oxidizing treatments and then retested. Changes as small as 0.01 dB in the reflection coefficient are detectable.

(2) Microwave measurements have been made on copper and iron foils.[7] In driving the foils acoustically, the experimenters designed the apparatus to provide a maximum 1 mm displacement of the foil from equilibrium. For clean copper and iron foils, that is, oxide free and therefore of extremely low resistance, the measurement of Q agrees with the calculated prediction for the geometry of the cavity. Driving the foils acoustically does not affect the Q of the cavity for either the clean copper or clean iron. This is not surprising since a change of 1 mm in the overall length of the cavity is negligible in its effect on the geometry.

If a lightly rusted iron foil is placed at the end of the cavity, there is an immediate change in the Q, compared to the value for clean iron. This change occurs for the foil at rest and is a consequence of the lossy nature of the rusty foil.

Driving the rusty foil acoustically at a frequency f_m causes a small amplitude modulation of the same frequency for X-band. The rust layers' thicknesses were 1 to 2 mils. Driving the foil acoustically strains the rust layer. Such strain introduces cracks in the layer that in turn affect the layer resistance. A strain change of $\pm 10^{-4}$ on either side of the unstrained state changes the layer conductivity by a factor of about 2. This causes a change in the planewave reflection coefficient of approximately 1 part in 1000. An effect is seen, therefore, when a rusty foil vibrates.

(3) They have examined the properties of rusty iron foils. From X-ray analysis they have determined the mixture of iron oxides making up the rust layer, and they have measured the strain sensitivity of the d-c resistance of these layers.

(4) They have correlated these results, including strain effects, with theoretical calculations.

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7. Bertoni, H. L., and Silber, L. M. (----) Strain Dependence of Rust Layers at X-Band, to be published.

5. CONCLUSIONS

The work reported here has shown that the phenomena that were loosely called RADAM does, indeed, fall into three broad categories: subsystem motion, switching effects, and junction effects. The subsystem motion includes periodic motions such as those of propellers and tank treads and structural vibrations such as wing flutter. The switching effects are due to the opening and closing of a junction as a vehicle moves. Finally, the true junction effect is a junction diode effect caused by the strain induced in composite conducting surfaces by vehicular motion.

The effect of subsystem motion is related closely to doppler effects and is indeed a special case of them. Rotational subsystem motions produce amplitude modulations, whereas linear oscillatory subsystem motions produce phase modulations. In general, these effects are some 10 dB below the skin line, which is the direct back reflection.

The switching effects are caused by redistribution of the surface current when a junction opens or closes. Recent work at SRI suggests that it may be useful in the field of target signatures. In general, this effect is some 30 dB below the skin line.

It is our opinion that the phenomena which comprise RADAM have been classified and investigated and are now understood in terms of basic physical processes. The junction diode effect is so weak compared with the skin line return, subsystem motion, or switching effects that it apparently offers no hope for signature work. Our general recommendation is that RADAM investigations be continued in the 6.2 area.

Now tnat the physical bases of the phenomena are understood, it is essential to determine those features of the observed spectra that may be unique and, hence, applicable to the target identification problem. This will require field tests with various targets and detection systems. From these tests, one can provide a broad data base and also determine the magnitude of each effect and the maximum range at which it is usable. This type of effort is underway under the supervision of AFAL.

References

1. Newburgh, R.G., and Borgiotti, G.V. (1975) Backscattered Spectra From Rotating and Vibrating Short Wires and Their Relation to the Identification Problem, Physical Sciences Research Papers, No. 633, AFCRL-TR-75-0298.

2. Newburgh, R.G., and Borgiotti, G.V. (1975) Short wire as a microwave analogue to molecular raman scatterers, Applied Optics 14:2727.

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